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Jorge Luis AMAYA*, Alan LELAH, Dr. Peggy ZWOLINSKI

Université Grenoble Alpes, Laboratoire G-SCOP, France
E-mail: jorge-luis.amaya@g-scop.grenoble-inp.fr

ABSTRACT
Product Service Systems (PSS) that create value by sharing or extending the use of products are expected to improve environmental performances of offerings. However, Lifecycle Analysis (LCA) which provides a comprehensive view and assesses the environmental impacts of products is not well adapted to PSS.
In this paper, an approach to help the environmental assessment of PSS using LCA during the design process is presented. It compares the environmental consequences of different PSS design alternatives and compares them to those in a hypothetical case of classical product sale replacing the PSS. The paper highlights characteristic requirements of PSS providing intensified use of products for multiple users. Next, a PSS lifecycle model is proposed to perform LCA during the design process. The parametric model constructed will help designers calculate and compare the environmental impacts related to various scenarios of alternative PSS offers. This will facilitate decision-making during the design phase because the PSS lifecycle parameters are identified and linked to PSS design characteristics. With this approach, actions can be easily identified and engaged to improve the PSS solution. A case study on bicycle sharing in the city of Lyon illustrates the approach.

Keywords: PSS, lifecycle assessment, design parameters, environmental impacts, intensified use.

1. Introduction

Confronted with market pressure and customers continuously demanding new technologies, manufacturers generate more and more products with accelerated obsolescence. However most of the components or products could be reused several times and/or shared by different users if we adopt a purely functional perspective of the required service. Taking into account these aspects, recent business strategies, such as PSS, are driven by the necessity to improve environmental performances in the production of goods and services (Mont 02, Tukker and Tischner 2006). Product-Service System (PSS) strategies integrate product and service offerings that deliver value in terms of use to the customers (Baines et al. 2007). A PSS is ‘a marketable set of products and services capable of jointly fulfilling a user’s need’ (Mont 02). This concept integrates services into a design space, dominated by physical products in traditional manufacturing industries and strongly focuses on how to fulfil customer needs and create customer value (Lindahl and Ölundh 2001). As a result, greater emphasis is placed on the use phase in the product lifecycle, including maintenance and other actions during the use of the product. Another aspect is that in many cases, the manufacturer maintains ownership of the product, supporting the function of the PSS and can therefore reuse, remanufacture or increase the lifetime of the products or components for greater profit.
However, even though PSS strategies have demonstrated their financial advantages, it is still necessary to prove their environmental viability in order to be considered as sustainable solutions. To adopt an environmental point of view, it is necessary to assess the PSS lifecycle to ensure that environmental impacts (EI) do not increase (because of, for example, maintenance processes or inappropriate use by customers). Indeed, such strategies could generate potentially non-negligible environmental impacts (EI) if they are wrongly implemented or generate appreciable environmental improvements when properly implemented. To be sure of their effects, PSS strategies have to be precisely described and specific models have to be developed to assess their environmental performance. All the authors mentioned above also discuss the potential environmental benefits of using PSS and generally agree on the fact that closed loop strategies, such as remanufacturing, reuse, standard components exchange, service selling, etc., tend toward sustainability (Vasantha et al. 2012). However, no research is known that attempts to collect all PSS design requirements and create a model for assessing PSS environmental performance. Indeed, design methodologies with the calculation of environmental impacts for ‘non classical’ lifecycle strategies do not exist (Gehin et al. 2009), and research focused on lifecycle assessment of PSS strategies does not lead to generic

models to assess the lifecycle of PSS (Lelah et al. 2011). Hence, even though PSS offers could be assumed to be environmentally friendly; it is still difficult to determine the benefits or environmental relevance of such strategies. Considering that some PSS business offers require the introduction or the extension of facilities to support the service offer (e.g. infrastructures, electronic equipment), it is not reasonable to assume that PSS will necessarily lead to reduced environmental impacts. Therefore, PSS have to be assessed from the environmental point of view by design teams to obtain real sustainable choices (Adler et al. 2007).

Thus, the objective of this paper is to provide a general methodology to model PSS and provide relevant lifecycle indicators for designers to help them quantify the environmental benefits related to PSS strategy. An approach is proposed to clearly establish environmental assessment of the PSS, focusing on the complicated use phase. The final aim is to be able to compare PSS approaches during design or to compare different possible PSS offers to the classical sale of products.

Section 2 defines and characterises PSS from an engineering point of view using a literature analysis to highlight the important characteristics of PSS with intensified use. Section 3 proposes an LCA model to calculate environmental impacts. The main parameters influencing the LCA are identified and described. After that, a case study is developed in section 4 illustrating how this model can be used. It concerns the PSS strategy adopted for bicycle sharing in the city of Lyon: Velo'v. Section 5 deals the limitations of the model in the context of design and discusses the relationships between the PSS engineering characteristics exposed previously and lifecycle parameters. The purpose is to help designers understand how engineering choices link to lifecycle parameters and hence to environmental impacts of the different PSS alternatives. Conclusions are presented in section 6.

2. Characterisation of PSS from an engineering point of view

This section characterizes the PSS offer by exploring different requirements developed in literature. The requirements have been regrouped in relation to the products, the services provided and finally the organisation of the PSS itself. The requirements will later be used to develop the PSS model to assess the environmental benefits from a lifecycle point of view.

PSS can be seen as a marketable set of products and services capable of jointly fulfilling users' needs (Doultsinou et al. 2009) (Tukker and Tischner 2006). This definition establishes PSS as a business model, in which companies replace the sale of products with the sale of functionality in the form of a service. In this strategy, manufacturing companies retain the ownership of their products and 'trade' the functionality to customers, for example on a relative 'per unit basis'. Their economic interest comes from the fact that the services provided by the product included in the PSS generate greater financial gains (Grönroos 2011). Sundin defines PSS as 'a change or a translation towards a higher degree of integrated product/service offerings instead of just physical products that can potentially be achieved with environmental benefits' (Sundin 2009).

Grönroos (2011) considers the intensification of product use as a major objective of the PSS. In this paper, we will define intensification of product use as a set of innovative principals introduced in the design process to support continuous use of the product. Indeed, PSS strategy often aims at the intensification of product use through the improvement of product availability or because multiple users make use of the same product during its lifecycle.

If PSS strategy can offer an opportunity to achieve sustainable business by implementing initiatives to develop appropriate business models and establish sustainable products, services or PSS (Pohl and Hirsch 2008), it requires careful consideration of all the parameters in the system, particularly when assessing this strategy from an environmental point of view.

2.1 PSS product requirements

Multiple use and multiple users imply that new requirements have to be checked and fundamentals revisited. Indeed, a product introduced in a PSS offer is not designed with the same requirements as products introduced through a classic business model (Maussang et al. 2009). Lifecycle-extended products highlight the aspect of sustainability by preserving the usability (i.e. the product's main functions) of the PSS offers (Meier et al. 2010), which can be achieved by a higher level of accompanying services.

In a PSS offer, availability and flexibility (Ritcher et al. 2010) are important parameters while technical specifications and tolerances (Morelli 2006) are more demanding. Moving deeper; it is necessary to verify process capability and the ability to respond to customers' specifications based on propriety knowledge of the interactions of all the product lifecycle actors (e.g. innovation, logistics, resources, firm performance, etc.) (Yang et al. 2009). When defining process capability, it is possible to relate capacity planning of the resources considered as support to the business model (Georgiadis and Athanasiou 2010). In product recovery networks, aspects of capacity planning are not only associated with the end-of-life of the products, they are also associated to other after-market supply chain issues (Mont 2002) (Kara et al. 2007). This clearly means that PSS offers with multi-users should integrate a robust system of recovery. Capacity planning also represents an interest for designers, who need to calculate the right capacity in a PSS offer seeking to replace the satisfaction offered by a product by a service. It is therefore important to undertake capacity planning of products and services.

On the other hand, a product for multiple users must be more robust. Robust product lifecycle management has to be developed to consider process and business systems with the objective of structuring robust product information and extending the lifecycle. Several approaches to robust products and services have been proposed (Kiritsis et al. 2003). Indeed, products in the end-of-use phase that are to be reused an unknown number of times must be solid enough to go through the recovery process and enter a new phase of use. Operating stability and robustness cause direct impacts on the quality of the product or system output (Geng et al. 2011) (Di Mascio 2003).

It has been noted that for lifecycle issues, modular design (Yu et al. 2011) also helps improve performance of the full product lifecycle. Modularity structure (Yu et al. 2011) could be considered from the beginning of the design process to improve the integration of new services into the system at the use phase (e.g. simplifying the maintenance service, the disassembly process and the reconditioning of components).

To complete this review of the main PSS product requirements that designers should take into account, other characteristics and requirements for products in PSS offers have been described in literature, such design simplicity and upgradability (Mont 2002) (Williams 2006, 2007). The requirements are summarised in table 1.

PSS requirements	Literature Review
- Prolonged product lifecycle	Kiritsis et al. 2003, Meier et al. 2010
- Process capability	Ariss and Zhang 2002, Yang et al. 2009, Georgiadis and Athanasiou 2010
- Robustness	Di Mascio 2003, Geng et al. 2011
- Availability and flexibility	Richter et al. 2010
- Technical specifications - tolerances	Maussang et al. 2009, Morelli 2006
- Modular structure and testing required	Yu 2011
- Design for disposal and technical obsolescence	Meier et al. 2010
- Upgradable	Mont 2002, Williams 2006, Williams 2007

Table 1. PSS product requirements

2.2 PSS service requirements

PSS strategy seeks to decrease the effort needed to make the system function while increasing the number of possible use phases. PSS models have to consider two main aspects: the function of the product, with the idea of satisfying the customer by providing the required service, and the related technical services to satisfy each customer and their specific requirements. Classic product sale models confer ownership to the customer so that planning and maintenance to optimise the product lifecycle are handled by the customers. Nowadays, customer requirements relate more to reliable preventive maintenance and technical support (Di Mascio 2003). Therefore both criteria must be considered from the start of the design process. In other words, technical support and preventive maintenance services are seen as strong contributors to PSS (Aurich et al. 2006) (Takata et al. 2004).

Another requirement directly connected to preventive maintenance is contractual facilities between the supplier and the customer (Richter et al. 2010). Advising and consultancy services are required in PSS strategy to provide advice on the added value obtained by the offer of a PSS. Advising and consultancy can be provided for environmental, management or maintenance concerns. Consultancy and advising is a way to foster close relations between producers and customers. For instance, the PSS offer will require advice or consulting in order to favour correct use (Williams 2007). The advice and consultancy provider will provide recommendations to focus on more efficient use of the product, provision of system consumables, etc.

Some PSS offers are designed for specific customer necessities. This means customisation of the services involves technology to accommodate the differences between the offers. Individual description must be carried out for each customised PSS (Schweitzer and Aurich 2010).

Customers' needs have to be translated into expectations. These expectations must be met by the delivery of functional results. Thus, basic results concerning the main function of components, modules or products have to be defined and improved at the use phase to justify the use of PSS (Maxwell et al. 2006). Finally, a list of requirements for services in a PSS offer is established in table 2.

PSS requirements	Literature Review
- Preventive maintenance - Customised service - Advising / consultancy - Delivering functional result	Di Mascio 2003, Aurich et al. 2006, Takata et al. 2004 Schweitzer and Aurich 2010 Williams, 2007 Maxwell et al. 2006

Table 2. PSS service requirements

2.3 PSS organisation requirements

The complementarities of product- and service-sale approaches suggest that the adoption of integrated product service offers could gain significantly from the introduction of sufficiently robust products that provide functional results for different customers (increased use during the product lifecycle) or user activities (customer behaviour). Whatever the product-service systems are, each one presents specific characteristics that must be considered in order to fully support meaningful delivery.
In environmental terms, PSS offer the opportunity for intensifying product use: the same product is used by several users (sharing), the availability ratio of the product is improved, or both (Maxwell et al. 2006). However, the gain of efficiency can be limited by user behaviour (Tukker and Tischner 2006). During the process of resource sharing, the PSS should conserve the same level of maintenance services as classical offerings with equivalent resource consumption in order to confirm lower environmental impacts. If this is not the case it becomes necessary to compare the impacts avoided by intensifying use with those induced by the installation of the new maintenance solutions (in terms of both services and products).
New requirements related to PSS have been identified in terms of engineering. These requirements are necessary to establish the products or services developed in the PSS offer to satisfy customer needs. Table 3 lists the requirements of PSS offers if they are to meet multi-user expectations and service designer needs.

PSS requirements	Literature Review
- Efficiency improvements - Consider the effects of user behaviour	Maxwell et al. 2006 Tukker and Tischner 2006

Table 3. PSS requirements

The important characteristics of PSS have been highlighted in this section to improve understanding of design and organisation parameters within a PSS. We will see in sections 4 and 5 that these characteristics can have a major influence on the environmental impact of the PSS. However, classic LCA approaches are not well adapted to PSS LCA, in particular because the functional unit (FU) that is the first reference for defining an LCA approach is difficult to establish. Therefore, the next section, presents our approach to establishing environmental impact assessment.

3. Environmental impact assessment for PSS

According to many authors, PSS offers could be considered as being environmentally friendly. However, it is still difficult to determine the benefits or environmental relevance of these strategies. Therefore, PSS have to be modelled and assessed from the environmental point of view by design teams to gain a better understanding of their overall performance. Environmental impact should be assessed in accordance with LCA methodology based on the ISO 14040 standards. However, ISO guidelines do not provide specific recommendations on how to proceed with the calculation of environmental impacts for 'non classical' lifecycle strategies (Gehin et al. 2009), and little or no research effort has focused on the lifecycle assessment of PSS strategies (Adler et al. 2007). In this section 3, an original approach is proposed to establish a clear environmental assessment of PSS, focussing on the complicated use phase. The aim is to be able to compare PSS approaches during design and also compare them to classic products. The starting point to establish an LCA according to ISO 14040 is the definition of the functional unit. Section 3.1 will describe the particularities of PSS FU definition. Next, the lifecycle model will be described and used to support calculation of the environmental impacts presented in section 4.
In what follows we will use 'product' for the principal elements of the PSS that replaces the 'product for sale' (as opposed to infrastructure and support equipment, for example).

3.1. Definition of the functional unit

To perform a PSS LCA and to compare alternatives, it is necessary to define the functional unit (FU). The FU is the core of lifecycle assessment. It provides a reference in terms of elements to evaluate and identifies the characteristics of those elements. As far as possible, the FU should relate to the functions of the product, service or PSS, rather than describe a physical product. In order to assess or compare a generic PSS offer with a classic product sale it is necessary to define equivalent FU. Thus, the FU characterises the PSS in terms of the main functions that the users want to obtain to satisfy his needs. Furthermore the FU must be able to respond to the design requirements described in section 2. With this in mind, this paper proposes to characterise the FU using the following elements of the PSS:

- **Service provision time** (t_{sp}): service provision time represents how long the PSS functionality must be available on the market (due to obsolescence).
- **Availability** (QS): this parameter describes the quality of the service in terms of the availability of the functionality offered by the PSS.
- **Conditions of use**: actual usage of the PSS functionality is represented by use during the product lives (i.e. the total time that all the products actually function during the PSS offering). The conditions of use are related to three factors: the average time for each use of the PSS functionality by each user (t_u): the average number of times the PSS functionality is used (n_u) by each individual user during the service provision time (the offer is designed to increase the number of times the PSS is used from an economic point of view); the number of different users (U) of the PSS functionality (the offer is designed for a certain number of users from an economical point of view. U represents a statistical or expected number of different users of the PSS functionality over service provision time).

In order to provide a comprehensive view of the system to be studied, the FU of a PSS should account for all these parameters. The different parameters proposed to characterise the functional unit come from the empiric observation of different PSS case studies. These parameters will lay the basis for designers to create different products, services and PSS scenarios and evaluate them from an environmental point of view (section 4.1).

3.2. Lifecycle Description of PSS

PSS strategy aims at the intensification of product use through improved availability of the product or through multiple users of the same product (Grönroos 2011). However, PSS strategy should not only be profitable, economically, but also from an environmental point of view. The purpose of this paper is to focus on the environment and it is necessary to assess the PSS lifecycle to insure that environmental impacts (EI) do not increase (e.g. increased maintenance processes or inappropriate use by certain customers). EI are calculated by examining all the processes involved in the lifecycle of the offering. They are commonly qualified or quantified by LCA or other methods. EI are expressed according to the impact category considered. For instance, global warming potential can be expressed as kg equivalent carbon dioxide/kg emission. The Eco-indicator 99 method uses single score ecopoints. Ecopoints are a composite measure of the overall impact of products, processes or service on the environment. They capture the relative harmfulness of different impact categories (global warming potential, acidification potential, radioactivity, etc.), combined to produce a single score (Renou et al. 2008). Ecopoints are preferred to other indicators derived from single environmental impact categories (e.g. the carbon footprint conclusions are based on the global warming potential) (Čuček et al. 2012). However, whatever impact and calculation methods are chosen, the PSS design lifecycle description will be the same.

A product lifecycle model for PSS is presented in figure 1. The figure portrays a temporal approach to describe the life of the products used in the PSS. During the product life, products move from production phases to use phases and finally the end of life phase. The different flows between the lifecycle phases are represented by arrows and each lifecycle phase is represented by a rectangle. Five generic phases have been used to model the lifecycle of a product in the PSS offer: Raw material extraction, Product manufacturing, Product distribution, Use phase and End-of-life. The EI in the raw material extraction phase ($EI_{raw\_material}$) include the EI of material extraction and transport to initial material processing as well as the EI of the preliminary material process and transport to the component manufacturing plant. The EI in the product manufacturing phase ($EI_{manufacturing}$) include the EI of the manufacturing process and transport to the product assembly plant. The EI in product distribution ($EI_{distribution}$) include the EI of transport to the customer. The EI in the use phase (EI_{use}) include the EI of resource consumption during use as well as any other operations assuring the availability of the service (e.g. maintenance, redistribution of products, etc.). Finally, the EI in the End-of-life phase ($EI_{end\text{-}of\text{-}life/use}$) include the EI of all recycling processes and the necessary transport. EI calculation of each phase of the product lifecycle will be described in section 3.4.

These classical product phases have to be completed by a deeper analysis of the use phase characteristics that can be affected by the PSS requirements in section 2 and the characteristics of the functional unit. In the PSS, use is intensified if unused time is decreased, that means, everything else in the system being stable, the total number of times that a product is used increases. Further characterising the intensification of use, the number of times the PSS is used is also influenced by the technical lifetime of the products necessary to run the PSS. The technical lifetime (t_{tl}) of any product used in the PSS is the average time during which the product is technically capable of providing required functionality. It is the time that the product remains in the use phase (the time between its entry to the PSS and the moment it moves to the end of life stage). There is obviously a relation between the technical lifetime and service provision time. If the technical lifetime is longer than the service-provision time then the products have the capacity to guarantee the PSS offer on the market during expected service provision. Otherwise, if service provision time is longer than technical lifetime, then the products used in the PSS will not be capable (robust enough) of supporting the offer during PSS market time. In order to maintain the same quality of service, new products capable of satisfying demands must replace worn out products, for as long as necessary to cover service provision time (figure 2).

To consider these aspects, the use phase is characterised by three stages (see figure 1):

- **Stand-by stage**: the products are not always in use (e.g. some products must be held in stock in order to insure availability). t_s is the time during which a product is on stand-by.
- **Use stage**: in the use stage, each single usage is characterised by a time of use (t_u). The number of times (n_u') each product is used during the lifetime of the product is considered. Service availability depends on both maintenance services and the potential surplus of products in the system to assure the QS.
- **Maintenance stage**: after each use, the product is either made available for further new use or will go to maintenance (for service improvement, to exchange broken parts or replace degraded units). The average percentage of products that go to maintenance at the term of each use is expressed by the maintenance ratio (α). The mean time spent in maintenance is t_m.

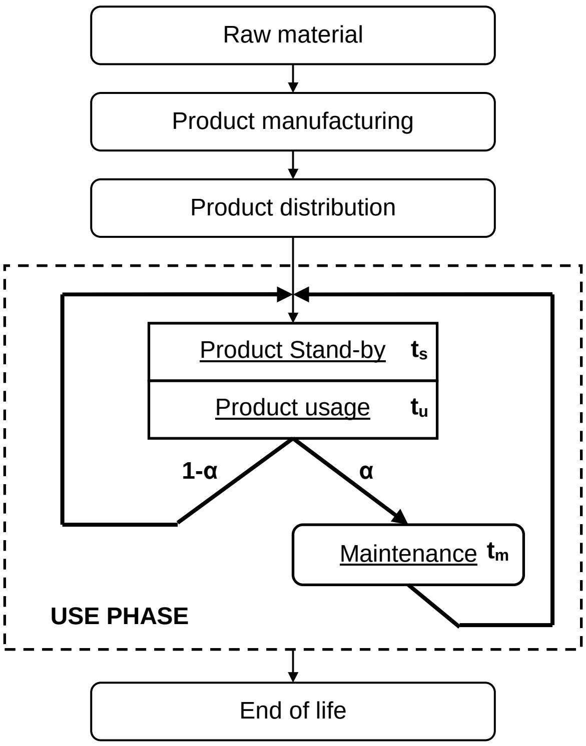

Figure 1: Product lifecycle for products in a PSS

Figure 2 represents different cases regarding technical lifetime scenarios and service provision time. In the first two cases, the technical lifetime of the products is able to support demand during service provision. In the third case the technical lifetime of the products requires more products with the same characteristics to ensure service provision.

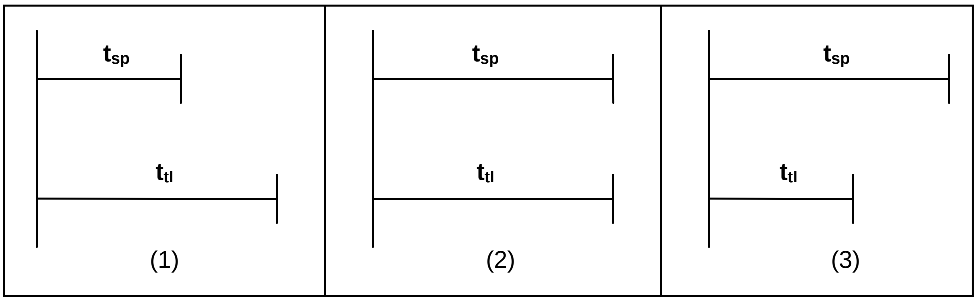

Figure 2: Technical lifetime (t_{tl}) versus service provision time (t_{sp}) product scenarios

To take into account the wearing effect of time, the total number of products necessary to run the PSS should be adjusted by a factor that considers the 3 scenarios (figure 2). We will call this factor τ and it will be determined by the relation between the service provision time and the minimum function of service provision time and technical life-time, as follows:

$$\tau = [\, t_{sp} / \min (t_{sp},t_{tl}) \,] \qquad (1)$$

3.3. PSS design considerations

In this section a set of equations to calculate environmental impacts are established to assist designers in defining 'non classical' PSS lifecycle strategies and control lifecycle properties. They follow a preliminary approach usable during the first steps of design and eco-design. The equations assume uniform average values of parameters although this can be considered as an important limitation to their precision.

To compare PSS strategy with other strategies such as the sale of a product, calculations are established for each average use of the products in the system. The total (optimal) number of products necessary in the system (N), for a given organization of the system, is expressed as a function of different design parameters (we suppose here that the designer will choose to optimize N to the minimum necessary).

Considering that each product in the PSS offer is, at each instant, either in use, on stand-by or under maintenance (see figure 1), N is a function of the number of products in use (N_u), products in maintenance (N_m) and products on stand-by (N_s) at any one time, as follows:

$$N = (N_u + N_m + N_s) \times \tau \qquad (2)$$

Furthermore, each term of equation 2 is directly related to the duration of each phase of product lifetime (use, maintenance or stand-by). N therefore depends on the average number of times (n_u') each user uses the PSS during the product technical lifetime (t_{tl}), given the average time for each use (t_u). It also depends on the average stand-by time of each product during one year of service (t_s) and the number of products under maintenance at one time. This last term depends on two parameters, the average percentage of bicycles that go to maintenance at the term of each use (α) and the average time each bicycle spends in maintenance (t_m). The number of products scheduled for maintenance depends on the robustness of the product, and optimisation of preventive maintenance should be regarded as an important organisational question.

Finally,

N_u is given by:

$$N_u = [n_u' t_u / (n_u' t_u + \alpha\, n_u' t_m + t_s)] \times N \qquad (3)$$

N_m is given by:

$$N_m = [\alpha\, n_u' t_m / (n_u' t_u + \alpha\, n_u' t_m + t_s)] \times N \qquad (4)$$

N_s is given by:

$N_s = [t_s / (n_u' t_u + \alpha\, n_u' t_m + t_s)] \times N$ (5)

The total number of times the PSS is used (U_T) during service provision time is determined by the average number of times each customer uses the PSS (n_u) and the number of different users (U), according to the expression:

$U_T = n_u \times U$ (6)

The average number of times each product is used throughout service provision time (n_u') is a function of the average number of times each customer uses the PSS (n_u), the total number of users (U) and the number of products in the PSS offer (N):

$n_u' = n_u \times U / N$ (7)

It should be noted that the equations above express total average times and integrate, without distinguishing between day-time, night-time, seasonal and other temporal differences that obviously can be present in the system.

3.4. Calculation of environmental impacts

During the design process, different lifecycle options are developed; it is necessary to determine the best one, or at least to avoid the worst ones for the environment. Literature studies on environmental assessment of PSS strategies list the potential advantages obtained by the evolution from classical product sale to products with added services (Mont 2002). Lelah et al. (2011) used LCA to show the benefits of a common telecom infrastructure for a waste collection PSS and highlighted the complexity to model the PSS lifecycle.

This section therefore seeks to assess the potential advantages of PSS offers considering the different elements of the system (infrastructure, stakeholders, etc.). Figure 3 shows possible resources that support the service offer during the use phase in the PSS offer. Here, the idea is to identify the main general parameters necessary to compare alternative PSS scenarios. Below, different equations are developed that define the impacts of each lifecycle phase using the lifecycle parametric model. Using these equations, a designer may identify how to reduce, control and monitor the most impacting phases and the related processes in the product lifecycle. It is clear that at this stage of the design process, parameters are not well established and there are uncertainties regarding the data. Nevertheless, it provides a useful quantitative tool for designers during the design phase.

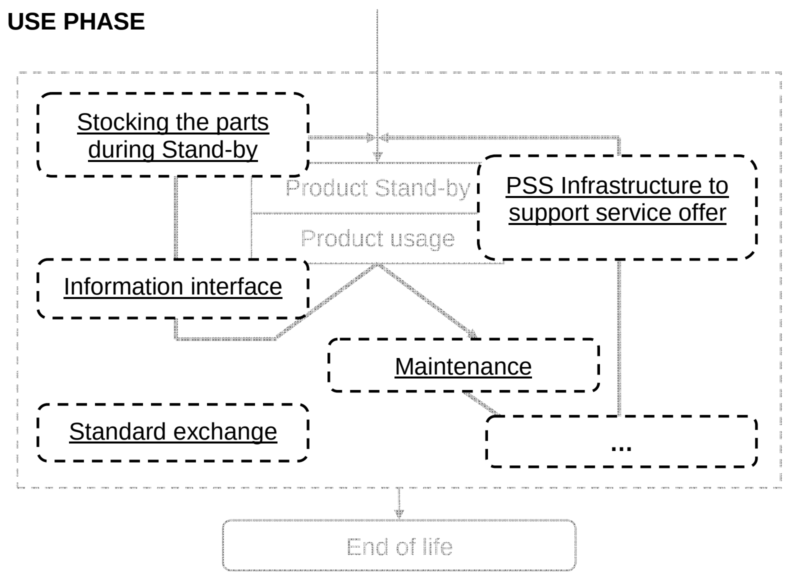

Figure 3: Services supporting the product use phase of the PSS

The environmental impacts of the PSS offer is evaluated using LCA methodology and the theory of lifecycle bricks proposed by Gehin (2007) and recommended for detailed evaluation of each lifecycle phase. Gehin considers the different end-of-life scenarios that calculate the environmental impact of each lifecycle phase depending on the end-of-life scenario chosen. This approach is applied here, using the parameters defined in the previous section. The environmental impacts of product-related and service-related activities and processes are allocated to each use of a product in the PSS offer. In this way, if $EI_{raw\_material\_product}$ is the EI necessary to extract material for one product involved in the PSS and $EI_{raw\_material\_service}$ is the EI necessary to provide the services, then $EI_{raw\_material}$ for one single use of the PSS is:

$$EI_{raw\_material}\ (1use) = [(N_u + N_m + N_s) \times \tau / U_T]\ EI_{raw\_material\_product} + [N_u \times \tau / U_T]\ EI_{raw\_material\_service} \quad (8)$$

If $EI_{manufacturing\_product}$ is the EI necessary to manufacture one product involved in the PSS and $EI_{manufacturing\_service}$ is the EI necessary for all material manufacturing for the services then $EI_{manufacturing}$ for one single use of the PSS is:

$$EI_{manufacturing}\ (1use) = [(N_u + N_m + N_s) \times \tau / U_T]\ EI_{manufacturing\_product} + [N_u \times \tau / U_T]\ EI_{manufacturing\_service} \quad (9)$$

A similar equation may be defined for the EI at the distribution phase:

$$EI_{distribution}\ (1use) = [(N_u + N_m + N_s) \times \tau / U_T]\ EI_{distribution\_product} + [N_u \times \tau / U_T]\ EI_{distribution\_service} \quad (10)$$

If $EI_{end\text{-}of\text{-}life\_product}$ is the EI necessary for the End-of-life of one product involved in the PSS and $EI_{end\text{-}of\text{-}life\_service}$ is the EI of the end of life of the services then $EI_{end\text{-}of\text{-}life}$ for one single use of the PSS is:

$$EI_{end\text{-}of\text{-}life}\ (1use) = [(N_u + N_m + N_s) \times \tau / U_T]\ EI_{end\text{-}of\text{-}life\_product} + [N_u \times \tau / U_T]\ EI_{end\text{-}of\text{-}life\_service} \quad (11)$$

If $EI_{use\_product}$ is the EI necessary for the use of one product involved in the PSS and $EI_{use\_service}$ is the EI of the services then EI_{use} for one single use of the PSS is:

$$EI_{use}\ (1use) = EI_{use\_product} + [N_u \times \tau / U_T]\ EI_{use\_service} \quad (12)$$

Following these equations, designers can determine the correct strategies for the different parameters. They can control variations in the EI of the products and services used in the PSS through parameters linked to the global organisation of the PSS. The parameters used in this section are summarised in table 4. These parameters describe the PSS lifecycle and their value can be modified by designers to optimise the system in terms of use, economics or environment.

	Parameters	**Definition**
PSS Lifecycle Description	t_{sp}	Service provision time
	t_{tl}	Product technical lifetime
	t_u	Average time for each use by each individual user
	n_u	Average number of uses of the PSS by each individual user during the service provision time
	t_m	Average time spent in maintenance
	α	Average percentage of products that go to maintenance at the term of each use
	t_s	Average time per year that the products are on stand-by (ready for use)
	U	Total number of different users of the PSS
	τ	Product replacement ratio depending on its technical lifetime **Eq. (1)**
	N	Total (optimal) number of products required in the system
PSS Design Considerations	N_u	Average number of products in use at one time **Eq. (3)**
	N_m	Average number of products in maintenance at one time **Eq. (4)**
	N_s	Average number of products on stand-by at one time **Eq. (5)**
	U_T	Total number of times the PSS is used **Eq. (6)**
	n_u'	Average number of uses of each product during the product lifetime **Eq. (7)**
Environmental Impacts	$EI_{raw\_material}$	Environmental impacts in raw material extraction phase **Eq. (8)**
	$EI_{manufacturing}$	Environmental impacts in product manufacturing phase **Eq. (9)**
	$EI_{distribution}$	Environmental impacts in product distribution phase **Eq. (10)**
	EI_{use}	Environmental impacts in use phase **Eq. (12)**
	$EI_{end\text{-}of\text{-}life/use}$	Environmental impacts in end-of-life phase **Eq. (11)**

Table 4. Parameters used in the lifecycle assessment of a PSS offer

4. Velo'v Case Study

In order to understand the subtleties of the proposed approach, the model has been used to evaluate the PSS strategy of the Velo'v offer in the city of Lyon. The Velo'v PSS offer was set up in May 2005. It is basically a bicycle rental system for people travelling in the central area of Lyon. A low cost season ticket (1 year to 1 day) is required to use the bicycles. Today, around 4,000 bicycles can be taken out from different stations in the city. In the present case study the hypothesis is that the Velo'v system starts with 2,125 bicycles.

A GPS system and pick-up trucks ensure that each bicycle station always has a sufficient number of bicycles available. A big advantage of this is that traceability and data available from the stations provide information on all the ongoing trips. Records provide details of the location and times of trips, as well as exact trip distances measured by counters on the bicycles. In 2005, the average trip distance per use was 2.49 km and the average trip time was 14.7 min. The Velo'v case is a typical case of PSS with intensified use involving many users and random use behaviour.

Due to the intensified usage of the bicycles compared to privately owned bicycles, the PSS strategy is interesting economically. However, no information exists on the environmental benefits that the strategy is able to generate. The method proposed above can be used to optimise the system from this point of view. The main objective of this study is to compare the environmental assessment of different design alternatives and to use the results during the design process to improve the characteristics of the system. The method supports changes in the business model or product requirements and opens new perspectives for designers.

4.1. Lifecycle in the Velo'v offer

Improving PSS strategy with intensive use requires the study of a diversity of design options in use-case scenarios. These scenarios allow designers to describe all the activities undertaken during the use of the PSS.

To simplify reasoning from a point of view of usage, the scenarios are specified by first choosing t_m, t_s and t_{tl} and then calculating N, the number of products necessary for each organization. Indeed, the standby time of the bicycles can be considered to reflect the availability of the bicycles (quality of service), while maintenance time reflects the choice of better maintenance instead of more bicycles. Similarly, the product technical lifetime reflects better, more robust products requiring more maintenance as compared to lighter fragile products. These first order considerations make important approximations by levelling out spatial (geographical differences across the town) and temporal (daytime, night-time and other seasonal differences) differences that are difficult to incorporate into the static model proposed.

The objective of the scenarios is to depict interactions between the customer and the system as well as within the system. Moreover, each activity has its own requirements taken into account during the PSS design process. For example, a scenario is developed where the customer does not accept a wait of more than 10 minutes to get a bicycle from any station in the system; this waiting time could be verified through observation. Requirements can therefore be considered as activity-related constraints. Another example could be the pick-up trucks that transport the bicycles between stations to maintain the availability of bicycles. Availability could be insufficient in certain stations during peak periods if there are fewer bicycles in the system. Redistribution of the bicycles could reduce this phenomenon. The transport used for maintenance is the same used for redistribution.

Within the PSS development framework the system lifecycle phases are linked to customer activities. The customer will interact with the system essentially during the use phase. It is during this phase that it is possible to understand the relations between customer activities and the elements of the PSS. For each customer activity, the designer will describe sub-activities, for example taking a bicycle out of the system or returning the bicycle to the system. In the Velo'v system, normal activities during the use phase include borrowing a bicycle, transiting in town with the bicycle and finally, returning the bicycle to a hiring station.

Following the description of the Velo'v offer above, the FU can be summarised as follows: 20,000 users in the city of Lyon (France); each user, on average, requires a bicycle twice a day for 15 minutes each time and the service must be available on the market for 12 years. The average percentage of bicycles that go to maintenance at the term of each use (α) is initially 5%; with an average time spent in maintenance (t_m) of 30 minutes. The average initial stand-by time is 41 weeks per year. With this definition it is possible to compare the environmental impacts of different scenarios. However, some explanations can help understand the scenarios:

- **Maintenance**: A the term of each use, 5% of the bicycles on the average will go for maintenance. Each bicycle under maintenance is blocked for an average of 30 minutes. This means that on the average, for every 20 uses of a bicycle, the bicycle will once go for a 30 minute maintenance service.

- **Standby**: This term can be understood if we consider that the bicycles are rarely used at night and on certain days (rainy days, holidays, etc.), for say, about half the time, or an average of 26 weeks per year. This means that at normal hours (about 25 weeks a year) the bicycles are used for 10 weeks and are on standby for 15 weeks. The ratio of use is therefore roughly 40% during normal hours. This term must be over-dimensioned during design to account for peak hour congestion.

The parameters that define the Velo'v scenario are summarised in table 5.

Parameters	**Units**	**Velo'v**
Service provision time on the market (t_{sp})	Years	12
Technical lifetime of the bicycle (t_{lt})	Years	1
Average time for each use (t_u)	Minutes	15
Number of uses during service provision time (n_u)		8,760
Average time spent in maintenance (t_m)	Minutes	30
Average percentage of products that go to maintenance at the term of each use (α)	%	5
Average time bicycles are unused per year (t_s)	Weeks	41
Total number of users (U)		20,000
Total number of bicycles on the system at any one time (N)		2,125

Table 5: Parameters for the Velo'v scenario

4.2. Initial environmental impact assessment of the Velo'v

The PSS model considers each component or module used in the system (product or service support) described in the introduction of section 4 and section 4.1. A database lists the EI of each lifecycle phase (raw material extraction, manufacturing, etc.) for each PSS item, including supporting services. The EI of the overall PSS lifecycle can in this way be automatically calculated using the different design parameters.

Figure 4 presents the initial EI assessment with available data using the PSS Lifecycle Environmental Impact Assessment model developed above in the case of the Velo'v scenario (named Velo'v 2005). EI are expressed in ecopoints and although they do not distinguish the diversity of environmental impacts, they are simple to use and are sufficient within the scope of this study. Computation considers all the components designed to support the service offer in the PSS strategy model. Material gains or losses are considered together with other relevant parameters such as distances between material and spare parts suppliers and the assembly plant, the type of transportation used, etc.

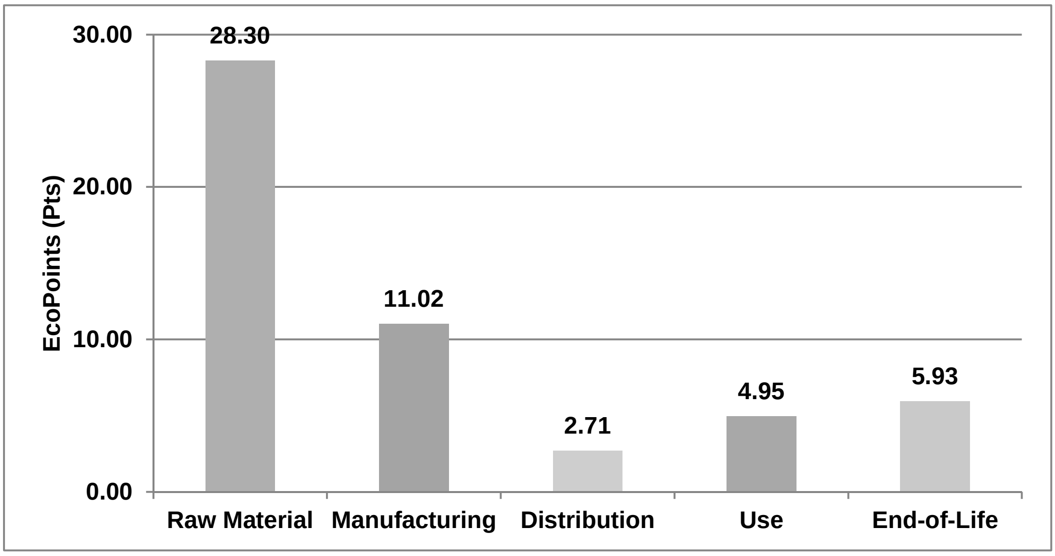

Figure 4: Environmental Impact for the Velo'v Lifecycle (EcoIndicator 99)

The initial model provides a first estimation of the global EI of the whole PSS structure as well as the impact associated with each product and supporting services. It determines the most significant product lifecycle phases influencing the environmental impact. The objective is to align decision making during PSS design with minimisation of global EI and optimal use of the product. In the present paper, the economic and social aspects are assumed to be treated apart as they require different tools than LCA.

4.3. Scenarios for the different PSS elements

Different scenarios representing different PSS strategies are possible for the system. To compare their EI, it is necessary to assess the EI of the products and the services. To understand the influence of the different parameters, their variations are tested in the following scenarios:

- **Bicycle robustness:** Considering the development of the Velo'v study case from the initial introduction of the service on the market in 2005, classical bicycles were initially used to meet customer needs. About one year later, most of the bicycles in the system had to be replaced by new products. This showed that the products were not technically robust enough and that their technical lifetime was greatly reduced due to the extreme use constraints involved in the PSS offer. In the beginning, the PSS requirements had not considered random use behaviour. The results indicated that the PSS significantly affected product technical lifetimes and a redesign of the product was necessary. Today, the PSS is provided with bicycles with a higher technical lifetime (3 years). This is obtained by modifying the critical components (e.g. mass and type of material).
- **Bicycle redistribution:** QS can be assimilated to the number of products available in each station at one time. This means that a certain number of bicycles must be available for potential customers. This condition can be met by introducing service units that redistribute the bicycles to critical stations at critical hours. This means that the system uses specific maintenance units to relocate the bicycles from the stations more than enough bicycles to the stations with an insufficient number of bicycles. Reinforcing this maintenance service, increasing redistribution, makes it possible to use fewer bicycles to maintain QS. The resulting overall number of bicycles necessary in the system is reduced. The variation can be significant if the redistribution of the products in the PSS effectively compensates the reduction of the technical lifetime of the bicycles due to more intensified use.
- **Bicycle maintenance:** The time spent in maintenance affects the technical lifecycle of the PSS. Due to different factors, such as random use behaviour or vandalism, the number of bicycles in maintenance may represent a significant proportion of the total number of products in the system. By concentrating maintenance efforts, i.e. by increasing the number of maintenance stations and preventive maintenance teams, the maintenance-time ratio will increase, leading to improved technical lifetime. Of course, in this strategy, a large centralised maintenance station might preferably be replaced with more, smaller stations in an optimum situation.
- **Combined scenario:** this scenario combines the results of the three previous optimisations. It shows that for intensified PSS use, QS and technical lifetime can significantly influence the environmental performance. Indeed, 'intensification within product lifecycles is considered crucial for dematerialisation, in particular, to design optimal PSS from the viewpoint of environmentally conscious design and manufacturing in advanced post-industrial societies' (Tomiyama, 2001).

All the scenarios seek to intensify product use while decreasing the PSS EI. In the case study, the intensification bicycle use is visible through the reduction in time on stand-by. This means that good organisation of the PSS can reduce the number of products in the system and, particularly, in each station, if good use is made of system historical records. The average unused time for the bicycles will decrease with more reliable products and better global management of the system.

4.4. Design parameters and environmental impact comparison

As stated above, the primary objective of the model is to establish the relationship between the generation of EI and reduction using different PSS strategies. In order to compare the effects of these strategies it is necessary to determine the EI relative to each average use, for the projected number of users, during a certain service provision time, while ensuring a certain level of QS. Each strategy requires a certain number of bicycles with different characteristics that limit the performance of the integrated service offer as well as the necessary network of integrated services (e.g. maintenance, guarantee exchange, etc.). Table 6 shows the design parameters described in the previous section compared to the basic Velo'v (2005). The parameter values have been estimated considering Velo'v as a baseline scenario and considering some of the requirements outlined in Section 2 depending on the scenario.

			Velo'v (2005)	**Bicycle robustness**	**Bicycle redistribution**	**Bicycle maintenance**	**Combined scenario**
Service provision time	t_{sp}	Years	12	12	12	12	12
Technical lifetime of bicycles	t_{lt}	Years	1	3	0.80	1.33	3.20
Time for each use	t_u	Minutes	15	15	15	15	15
Number of uses by each user during service provision time	n_u	Number of uses	8,760	8,760	8,760	8,760	8,760
Maintenance time	t_m	Minutes	30	30	30	30	30
Ratio of bicycles going to maintenance after each use	α	Percentage	5 %	5 %	10 %	10 %	15 %
Bicycle stand-by time per year	t_s	Weeks per year	41	41	34	40	33
Number of different users	U		20,000	20,000	20,000	20,000	20,000
Total number of bicycles in the system (during service provision time)	N		25,500	8,500	22,083	19,500	5,677
Number of uses of each bicycle during its lifetime	n_u'	Number of times	6,871	20,612	7,934	8,985	30,862
Number of bicycles available in the system (at one time)			2,125	2,125	1,472	2,167	1,514

Table 6: Parameters for the Velo'v scenario

The first alternative scenario, 'bicycle robustness", seeks to increase the technical lifetime of the bicycle (from 1 to 3 years). The bicycle components that break down more frequently are identified and redesigned for more intensive use (robust design generally increases the mass of the components). Initially, the Velo'v bicycles were normal bicycles and because of the harsh conditions of use, they broke down after about one year's use. Redesign of the bicycles enabled the new bicycles to last 3 years under the use conditions of the Velo'v service. The prolongation of the technical lifetime results in a reduction in the total number of bicycles required in the system (from 25,500 to 8,500). However, increasing the mass could also affect maintenance operations, but this was not taken into account in the study.

In the next scenario, 'bicycle redistribution", bicycles are moved to critical stations, by increasing maintenance, in order to optimise stand-by time. Here again the total number of bicycles necessary in the system is reduced (from 25,500 to 22,083). It is important to notice that redistribution will affect the product lifetime because of intensified use. In the case presented in the scenario, lifetime is reduced from 1 to 0.8 years.

The third alternative scenario, 'bicycle maintenance", optimises organisation. By increasing the maintenance rate (from 5% to 10%), it is possible to improve the lifetime of the bicycles. Once again, the total number of bicycles necessary in the system is reduced (from 2,550 to 1,950).

The last alternative scenario combines the three strategies to obtain a more significant gain. The maintenance rate is increased (from 5% to 15%) to account for both maintenance and redistribution. The technical lifetime of the bicycle also increases (from 1 to 3.20 year) with more robust design and better maintenance even though there is a drop due to intensified use. The total number of bicycles necessary in the system is drastically reduced from 25,500 to 5,677. The combined scenario is feasible and, considering the environmental advantages, could replace the previous scenarios. The case study shows how it is possible to compare several design requirements to an initial scenario using the method. The case of multiple scenarios illustrates the advantages of different strategies.

Once the design parameters defined, the EI can be computed for the products and other resources used in the PSS offer. A simplified assessment was made with the LCA software, SimaPro, using the Eco-indicator 99 method. Next, the values obtained from the software were compiled using equations (8) to (11), automatically calculating the EI for one use of the product.

Figure 5 presents the comparative EI between use of a 'personal bicycle" (product sale) and the introduction of the Velo'v PSS in 2005 and the four scenarios described above (i.e. bicycle robustness, bicycle maintenance, bicycle redistribution and the combined scenario). Personal bicycle use describes a scenario where each user owns their own bicycle (i.e. 2,000 bicycles for 2,000 users) and

includes estimations for certain elements of the service per bicycle used in the infrastructure (e.g. bicycle routes). The environmental assessment of the personal bicycle scenario used LCA methodology (software SimaPro) and the Eco-indicator 99 method.
Figure 5 shows the results of EI calculations for the complete lifecycle of the service and for each scenario (from raw material extraction to end-of-life). In order to be comparable, the EI have been calculated with 'a single use' in the functional unit as prescribed in Section 3. In this way, it is possible to compare the use of a personal bicycle with a PSS offer.
The personal bicycle use case: This case is a projection of reality due the complexity of the model of real use of a bicycle. Classical bicycles will meet similar customer needs as in the initial Velo'v case. This means; 20,000 users in the city of Lyon (France); each user, on average, requires a bicycle twice a day for 15 minutes each time and the service must be available on the market for 12 years. This scenario differs to the other scenarios as far as availability (QS) is concerned: the bicycle is 100% available. The average percentage of bicycles that go to maintenance at the term of each use (α) is low, we take 0.20% (empirical value); with an average maintenance time for the bicycle (t_m) of 60 minutes by year. The scenario also assumes a technical life time of 6 years for each bicycle.

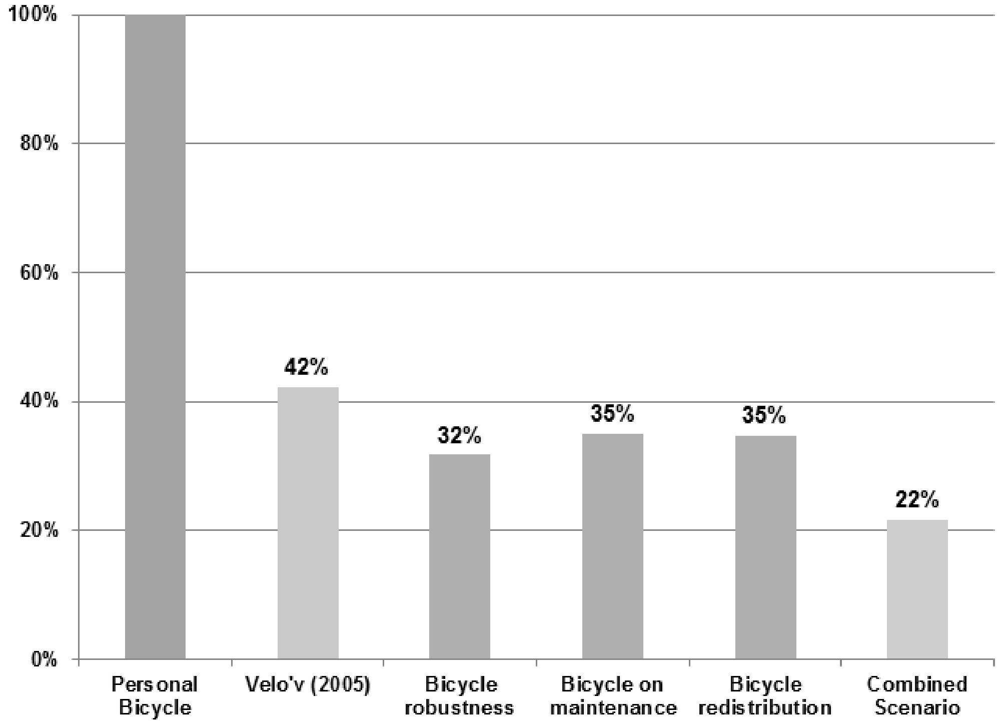

Figure 5: Environmental Impacts Scenario Comparison PSS

The results show that the introduction of the PSS offer (Velo'v 2005) produces a very significant reduction in the EI. This means that the introduction of intensive usage in the PSS largely compensates the impacts of the infrastructure elements to support the service. A 58% EI reduction is obtained.
Further reduction of the EI depends on the alternatives chosen. Figure 5 shows that, for the strategies applied in the case study, the benefits obtained by redistributing the bicycles in the city are equivalent to those obtained by optimising the bicycle maintenance chain, but less effective than the robust strategy. The combination of the three alternative strategies would give the best results with a reduction of about half of the EI of the Velo'v 2005 system.
Even if the use phase shows relatively low EI compared to the raw material and manufacturing phases (figure 4) the use phase strategy of the global PSS affects all the production and raw material phases and determines the outcome of the overall EI of the PSS. This shows that a good use stage strategy can significantly reduce material consumption of the PSS.
The following section discusses how the design parameters interact with the PSS and affect design decisions in the case study.

5. Discussion

This paper treats the question of LCA to design PSS for intensified use. PSS can represent very complicated organization, as in the case of Velo'v where random use of bicycles dominates. During design stages precise details of use are ever more difficult to obtain and the designer has often only a blurred vision of how the system actually would work. On top of this the designer has to envisage scenarios that sometimes involve important structural changes concerning the PSS. For example in the case study, the infrastructures necessary in Lyon to run projected maintenance services are very difficult to define precisely. Many limiting hypotheses had to be made. Nevertheless the designer needs simple tools in order to characterize important environmental questions and support design choices. In this work we opted for a preliminary static model to describe the system despite severe theoretical limitations. Many hypotheses had to be made on average use behaviours. It is sure that a dynamic model would have led to more precise calculations for a particular well defined PSS, supposing that all the characteristics were known and available for the designer. However this is not the case, especially during the design stage. In addition the designer needs to understand the parameters he uses and rapidly understand their effects on the whole system. PSS are more complicated than simple products and eco-design requires an intuitive approach. The case study shows however that the static model does provide useful indications of what directions can be considered to improve the system, environmentally speaking.

Of course the case study is purely hypothetical as it would have been necessary to be present during the design stages of the PSS to support the designers. This is another limitation of the study conducted here. It would be necessary to apply the principals to a real case of PSS design.

Furthermore, the model was elaborated for the case of bicycle renting. Other use intensive PSS cases may have different characteristics. There could be fewer products involved or more complicated technologically. The issues may not be the same. The principals used here should be tested with other types of use intensive PSS.

Finally, to resume, a more articulated validation should cover real time design issues and a variety of PSS design cases. The static model should be used to guide development of more precise dynamic models that cover random parameters such as user behaviour that is all the more important for PSS offerings as compared to classical product sale.

Another issue that will often arise when dealing with environmental considerations is their possible extension to economic questions. This is true for PSS as for classical product sale offers. While it seems clear that the model can be used if economic measures, like cost, are replace the environmental indicators, the economical question covers many other types of costs like hidden costs and other financial considerations that are out of the scope of the work presented here. For example in the case of Velo'v, without going into precise details, the financial profitability of the system is assured by J. C. Décaux who supports the PSS in exchange for the control of publicity panels in Lyon.

In spite of all these drawbacks and limitations, the paper suggests how designers should integrate environmental factors and lifecycle considerations to eco-design PSS with intensive use.

A PSS is often described as a system which includes physical objects and service units (Maussang et al. 2009). These two elements have to be structured by the PSS supplier in order to match supply and demand correctly. Therefore, organisational links have to be defined within the PSS. Finally, a full picture of the PSS must include the physical objects and service units (system elements) as well as the links used to coordinate the offer correctly (system organisation).

Correct operation of the system requires clarifying the limits of the relations and the existing frontiers between the PSS elements. The activities carried out in the system are executed by a combination of physical objects and service units while system organisation links and coordinates service delivery. The role of organisation should be viewed as the management of a set of relations existing between system elements.

Following on this idea, it is necessary to identify the main actors and partners involved in the PSS. Indeed, for the service to progress correctly, it is necessary to integrate all the partners within the system and detail the roles of each actor. Figure 6 introduces the users and illustrates the different elements forming the system as well as the relations that exist between them. It suggests that to precisely define the installation of the PSS and support choices during the design of the global system, for a given population of users and usage habits, the organisation must determine the optimal combination of service units and physical objects and their operation within the system.

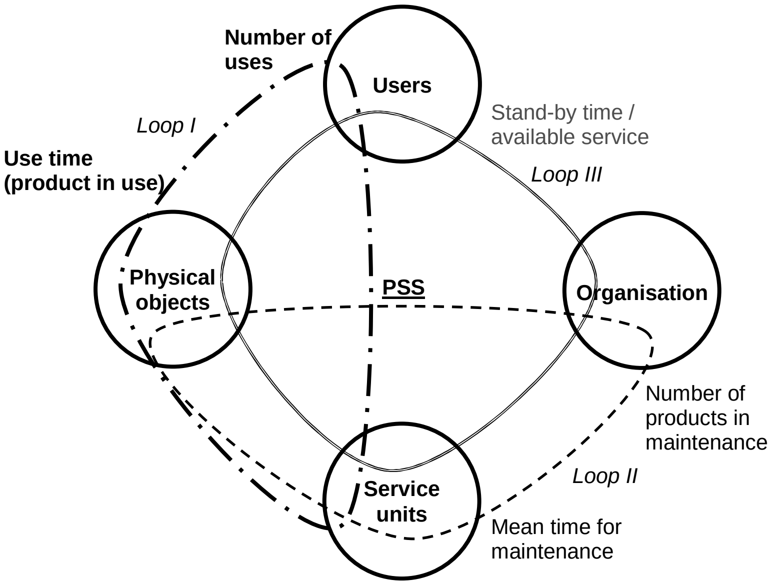

Figure 6: Characterisation of the system – PSS use phase

Figure 6 also shows three loops. ***Loop I*** adjusts the number of physical objects and service units to the number of users and uses (number of uses, use time – see equation 3). ***Loop II*** highlights organisation of physical objects and service units to provide operational services such as preventive maintenance (mean time for maintenance, number of products going to maintenance – see equation 4). ***Loop III*** insures global synergy of the PSS elements to guaranty availability of the services for the users (stand-by time / service availability – see equation 5). Observing the loops closely, the indicators that characterise the system are equivalent to the main parameters of the PSS lifecycle model used for the environmental assessment.
In the case study, the different scenarios are compared from an environmental point of view. The same parameters have been used to characterise and define the two systems: shared bicycles and individual bicycles. The Velo'v solution seeks to intensify the use of the bicycles. This means the Velo'v solution reduces the number of bicycles necessary to provide the required quality of service to the users. However, the lifetime of the bicycles is reduced due to the intensification of use whilst maintenance must be increased to ensure availability. System requirements should be connected to product lifecycle parameters to create coherent alternative system design scenarios. The relations between technical features and design parameters are presented in table 7.

	Design Parameters						
Associated Features	n_u	t_u	t_m	t_s	t_{lt}	t_{sp}	α
Prolonged product lifecycle	+	+			+	+	
Robustness (increasing mass)					+		+
Technical PSS specifications	+	+	+				
Technical obsolescence	+				+	+	
Reliability	+	+	+	+			+
Preventive maintenance			+			+	+
Delivering functional result		+					

Table 7: Effects of strategy requirements on the PSS design parameters

In the bicycle robustness scenario, the bicycle is redesigned for more intensive use (robust design will generally increase the mass of the components). The weaker bicycle components are identified (gears, pedals, frame, wheels, theft, easy seat adjustment, etc.) and redesigned to increase robustness. The technical lifecycle of the bicycle (t_{lt}) is extended, and the expected percentage of bicycles that go to maintenance at the term of each use (α) due to broken parts or degradation after use is influenced by robustness. In addition, other features are also related to the lifecycle parameters. Redesign of the weaker components also influences some of the technical specifications of the PSS: the number of uses (n_u), the time for each use (t_u) and the mean time spent in preventive maintenance

(t_m). Finally, the prolonged product lifecycle must be crossed with the number of uses (n_u), the time for each use (t_u) and the service provision time (t_{sp}).
Regarding bicycle redistribution, the number of bicycles in each terminal is readjusted to reduce stand-by time (t_s). Moving the bicycles from where they accumulate to where they are needed will influence some of the features presented in table 7: the percentage of bicycles that go to maintenance at the term of each use (α) is determined by the moving trucks that retrieve bicycles and send them to maintenance and reintroduce them after maintenance. The technical lifecycle of the bicycle (t_{lt}) tends to decrease because of intensified use and depends on the total number of bicycle uses by each different user (n_u) and the overall service provision time (t_{sp}).
Finally, in the example of the bicycle maintenance scenario, in table 7, organisation improves maintenance to increase the bicycle lifetime. Firstly, increasing lifetime by maintenance means increasing the percentage of bicycles that go to maintenance at the term of each use (α), secondly features like technical obsolescence, delivering functional result and reliability are controlled better and enable adjustment of the time for each use (t_u) during specified service provision time (t_{sp}) with the desired stand-by time (t_s) of the offer.
Finally the loops in figure 6 resume the keys to optimise the system. Optimisation will focus on the environmental impacts in our case study, but other criteria could be supported by this model (costs, number of people involved in the PSS, lifetime, among others).

6. Conclusions

PSS has a real potential to improve resource sharing with intensified use even in the case of random user behaviour. For this, it is necessary to ensure and extend the lifetime of the supporting products. A literature review was used to determine needs and elements to be taken into account and support designers choices a priori. Preventive maintenance, customised services, capacity planning and product robustness are decisive factors that must be designed correctly. However, the conditions to reduce environmental impacts are not simple to demonstrate and no robust lifecycle assessment methodology to compare alternatives was previously known.
This paper presents a static model for the environmental lifecycle assessment of PSS with intensified use and multiple users. Design parameters take into account the main design characteristics. They simplify the environmental evaluation task and support design decisions more conveniently. The limitations of this model have been discussed.
The model has been successfully applied to Velo'v, a PSS case of intensified use with multiple users and random use behaviour. To cover the environmental dimension of PSS; the case study shows that it is now possible to study and compare the environmental impacts of different alternative scenarios. Even though the use phase shows relatively low environmental impacts compared to other phases, the use phase strategy of the global PSS strongly affects the other phases and determines the outcome of the overall environmental impact of the PSS. A proper use-stage strategy can significantly reduce material consumption of the PSS.
PSS strategy represents an excellent opportunity to improve sustainability. However, it requires careful consideration of all the design parameters in the system. The model developed in this paper considers the importance of the use phase in the PSS lifecycle. From the work described herein, the following conclusions may be drawn:

1. A list of requirements for a PSS has been defined and is flexible enough to help designers create new scenarios of use according to the gains obtained in environmental terms.
2. The environmental impacts for the whole system depend on the products (technical lifetime, reliability, etc.), the services (preventive maintenance, stand-by time, etc.), but also on the global organisation of the PSS (number of users, number of uses, etc.). A model that can be used to simulate alternatives has been proposed.
3. The intensification of use can be an important factor to improve the environmental impacts of the PSS.

The results suggest that care is needed during the PSS design process at the use stage. Special attention must be given to design parameters as well as environmental impact assessment to select an appropriate number of products in the PSS from an environmental point of view.
Further development should formalise the approach with software to be used in an industrial context for the design of PSS offers. Indeed, PSS is a promising strategy and needs methods and tools for developing strategies used during the product, process or lifecycle design. It is possible to apply this approach to other products with closed loop strategies to help designers make decisions during the design process while taking into account environmental concerns.

PSS seeks to improve the use phase through different services such as intensified use or improved maintenance. We now have an approach to show that if this strategy is properly implemented, a drastic reduction in the overall impacts on the environment for each use can be expected.

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